FRIENDLY SABOTAGE IN MACHINE SAFEGUARDS AND THE ROLE OF ENGINEERING AND PLC'S TO STOP THIS

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ABSTRACT

Heavy machinery can cause great damage to the human who gets too close to the processing stage. For example: a finger can be cut off in a metal punch press; a hand can be cut off in an automated assembly line; holes can be drilled into the human body by industrial grade drill presses, milling machines and lathes. By modern safety laws, all heavy machines must have safeguards to prevent these types of accidents: cages or barriers to prevent the human's entrance to the processing stage or automatic disconnects to shut down the machine when a human's presence is sensed as being too close. But all too often these safeguards are sabotaged by the very workers they are meant to protect. Without safeguards, the worker can work faster, but the absence of safeguards eventually causes an accident. We study several cases and show that better engineering of safeguards is the only way to prevent these types of accidents. Engineering students who study these cases learn that not only is it necessary to know how to design a PLC or industrial control to safeguard the worker, but also they must design them in such a way as to thwart friendly sabotage. Improved design techniques include: better interlocks for shut-down controls and more rigid specifications for self-regulated safeguards.

INTRODUCTION

Heavy machinery is a part of the modern world. We require a great variety of products, from cars to jets, and these products cannot be made available to the masses without heavy machinery.

A modern machine shop contains many old machines; they are still in use, and they are productive. We have seen milling machines built during the 1940's that are still in use. This makes sense. They have extremely heavy steel construction: they will never wear out (or so it seems). These machines sit next to their modern counterparts, and often it is the modern machine that has less steel and less resilience to the duties it must perform.

There are two common denominators between old and new machines. All machines need to be modernized so as to produce more and better parts. This often means computer control. Also, all machines need to be upgraded to account for the safety of the workers. It is always a good thing to keep your workers safe. But now more than ever, safety is not just a moral imperative, it is also good business, since an injured worker can go to court and obtain a large financial settlement. The biggest problem here is the person who must work on a particular machine. If a safeguard slows them down, then it is often sabotaged to speed up production. This can be a function of worker laziness or a worker's fear of losing their job.

We discuss 3 cases of worker sabotage and their outcomes. We see that programmable logic (PLC) control is the preferred method of increasing worker safety [1], but it is not the only method.

CASE 1: MAN LOSES 2 FINGERS IN AN INDUSTRIAL PUNCH PRESS

There is a company in Georgia that does a variety of machine jobs on special order. They employ a heavy punch press to punch metal. Up to 1/16 inch metal plate can be punched quickly.

The machine itself is strong. It is heavy gauge steel, built in the 1950's. The likelihood of a piece of this machine breaking or falling off and hurting someone is almost zero. Under the protocol of the job being done, a worker places a blank metal piece on to the stage for punching. There is a light curtain surrounding this stage. A light curtain is a series of LED's and pin diodes. The first LED is oriented to give off a light beam straight up. A pin photodiode is locate approximately a foot above this and receives the light from the first LED. About 2 inches to either side of the LED is a second LED with a second pin above it. This continues all around the stage. If we think of each light beam as a bar, these light beams together form a sort of jail cell around the active stage. See Figure 1. If a worker puts his hand through these beams, he will break one or more of them. This shows up as a signal NOT received at the pins. This signal (or lack of signal) goes to the control unit and tells the controller to shut down the machine. Even though these LED's/pins form a cage, the cage is called a light curtain in industry. See Reference [2].

It should also be noted from Figure 1 that there is a worker in the picture aligning a piece for processing; she is breaking several of the beams, and the machine appears to remain ON. There are several adjustments to light curtains called MUTE and SENSITIVITY. Mute allows for the breaking of one or more beams without causing the machine to go off. Sensitivity can be thought of as a delay to a broken beam. If the sensitivity is too high and if I merely wave my hand near one of the light beams, then the whole system shuts down – the system goes off even though the worker is in no danger. On the other hand, if the sensitivity is too low, the worker can break beams and have his hand in the staging area for a very long time with the machine running – this would certainly cause an accident. In the ideal machine, the sensitivity and mute controls are such that the beams are strongly regulated to allow flexibility but NEVER compromise human safety.

There was a light curtain manufactured in California in the 1980's that could be set by the worker to have so little sensitivity, that a machinist could poke his hand through the curtain, spend a second or two adjusting a piece on the stage, and get his hand out without setting off the controller. The control unit was deemed too easy to sabotage. California outlawed the unit by 1990. From the worker's stand point, this control unit was good. He did not have to shut down the machine. If he were quick, he could put a metal blank on the stage quickly, get his hand out of the way, the machine would punch the piece, he then quickly removed it and put in a second blank, the machine punched this one, etc. His productivity was high, and he had free time to relax, whereas other workers took much longer to meet their quota. The safe worker had the sensitivity set high; he broke the beams when he put his hand near the stage to put in a metal blank and remove the previous piece; this shut down the machine; he would press re-start after his hand was away from the light curtain. This process added a few seconds of repetitive work to an already boring job. The temptation to sabotage was deemed too great. Added to this was the stream of complaints and accidents resulting from the use of this control unit. Hence, it was deemed “against the law” in California in 1990.

At this point, one might argue that automation is the answer to this problem. By developing a fully automated assembly line, the job could have been done safely and quickly. A 1000 pieces could be punched in under an hour. The problem is that the entire job in question was 5000 pieces. Setting up an assembly line costs tens of thousands of dollars and weeks of time to prepare. Small jobs are set up, run, and disassembled. These small jobs invite unsafe conditions and accidents. Yet, these small jobs are the backbone of most modern small shops: this week, you are making 1000 plates for Ford Motor Co.; next week, you are punching 200 metal name plates for the local church. You are a job shop, and you must be ready to adapt your shop to the next job order that comes in. For a job shop, safety must be built into the safeguards that control the machine being used. Granted worker training and classes on safety are important, but they can easily be defeated by a worker who is afraid or lazy or both. See [3].

The second controller produced by the California company was much better. Granted, one could disable any safeguard by simply unplugging it and putting it on the shelf. But such an obvious sabotage is generally easy to catch, and certainly it is not the topic of this paper since it entails human management rather than scientific protocol; in order to sabotage this second controller, you had to remove the unit physically from the system. The sensitivity of the curtain to light fluctuations was improved so that it no longer required adjustment by the worker. The earlier light curtain controller had used DC current to power the LED’s. This DC was read by the pins. With ambient light changes and the movement of shadows, this control was fraught with problems. It was either too sensitive or not sensitive enough. Even a safe worker could be guilty of adjusting the sensitivity too low. The new controller came with a power supply that still used DC to power the light curtain. However, added to this was a high frequency (1000 Hz) AC signal to modulate the light intensity. It was this high frequency light that was analyzed at each pin to determine if there had been a break in the curtain. Ambient changes in light no longer effected the curtain.

But pertinent to the topic of this paper, the new controller was “robust”. As anyone who has taught a course in control theory knows, “robust” defines a system that is NOT sensitive to wide fluctuations in its input parameters. In the case of a light curtain, the ambient light was defeated by a 1000 Hz modulated light beam between pin and LED. But also, adjustments to the sensitivity of the beam were pre-determined via PLC (programmable logic control) to fall within certain safe operating ranges. The user must power up the unit, but after that the user was at the mercy of the control unit, and only those changes could be made in the system’s operation as were deemed to be safe to the work. Both the mute box and the sensitivity control were gone. Much of the previous flexibility was taken away from the machinist and placed into the hands of the safety engineer who was responsible for setting the operation of each control. One might argue that if the safety engineer were corrupt, this would still lead to trouble. However, even his power was limited to a pre-set range of industrial controls implemented at the PLC level.

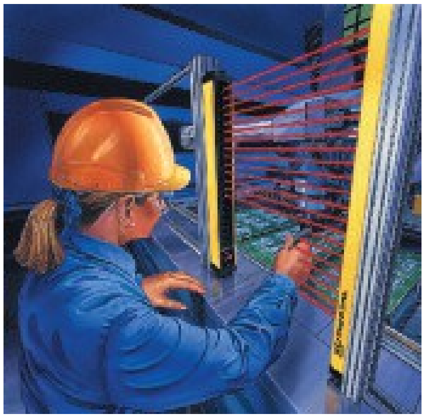


Figure 1 shows the light curtain in operation. The lady in the picture is breaking the curtain in 3 to 4 beams. Under proper control, the machine is stopped dead. Nothing will happen to the lady. If the sensitivity is reduced then the breaking of the beams may not even register, and the machine will remain on. This was the case during the accident. Also, some machines come with a feature that the machine can be on while the machinist breaks one or more beams. This is called blanking. But once again, if “blanking” is set by the machinist, she can set it to too large a value and cause an accident. Or if it is controlled properly by the PLC, then the blanking would only be good to the limits that are deemed safe for the worker.

The new controller was deemed safe by California law. The old controller could no longer be sold. The logical choice at this point was for the company to scrap the old controller. Instead, they sold them out of state. In 1995, one of these old controllers was being used on a heavy punch press in Georgia. To speed production, sensitivity was set too low on all machines in use in the shop. Eventually, one worker ran out of luck. He had two fingers cut off when the punch came down on a piece that he was still holding.

Even though it did not violate Georgia law, the company where the accident occurred and the company in California that produced the controller were found liable for the worker’s injuries. They were also forced to issue a nationwide recall of all of their “first generation” controllers. The old controllers were replaced free by the “second” controllers they were making.

CASE 2: A WORKER CLEARS A JAM FROM A MACHINE AND GETS BOTH HANDS CUT OFF.

In Long Island, a machine shop is equipped to produce “bubble” packages. Normally, when you go to the store to shop, you may see an item (for example nail clippers) in a package. The back of the package is cardboard. The front is a clear plastic bubble that encloses the clippers but lets the customer see what they are buying.

If a large company (like Johnson and Johnson brands) produces a product, they can spend the time and money to build a large assembly line to package a thousand nail clippers per hour. Safety is still an issue, but the idea of worker sabotage is almost nonexistent. But what if you are a local podiatrist? Business is good. You would like to give away free nail clippers as a business promotion. You want to advertise your service. You get a cardboard backing with color printing saying something like “Dr. John Doe’s podiatry, 123 Main Street”. The nail clipper goes on the cardboard and the bubble is wrapped around it to form a tight see-through package.

A machine used to perform this service is a Thermoformer. The machine heats a plastic sheet to make it malleable. The sheet comes off a roll (similar to a roll of toilet paper). The cardboard with the clippers enters the staging area, the plastic is heated and pressed down on to the cardboard around the nail clippers, the plastic is then cut with a guillotine like blade that comes down to separate the plastic on the cardboard from the plastic still on the roller.

This machine had a double safeguard. First, there was a metal cage around the area where the plastic was thermally pressed and cut. Second there was an automatic stop switch that killed the machine completely. Both of these were defeated easily.

In the first case, a spring loaded micro-switch was placed near the point where the cage was lifted by the operator. When she lifted the cage to put her hand into the area of the stage where the pressing and cutting was done, the spring switch was triggered and the machine was shut off. However, this switch was in full view of the operator. By simply holding the switch down, she could lift the cage up without the switch shutting down the machine. In fact, the spring lever controlling the switch could easily be bent to a point where it was no longer nestled near the cage. Hence, the movement of the cage no longer triggered it in any way. See Figure 2.

Figure 2

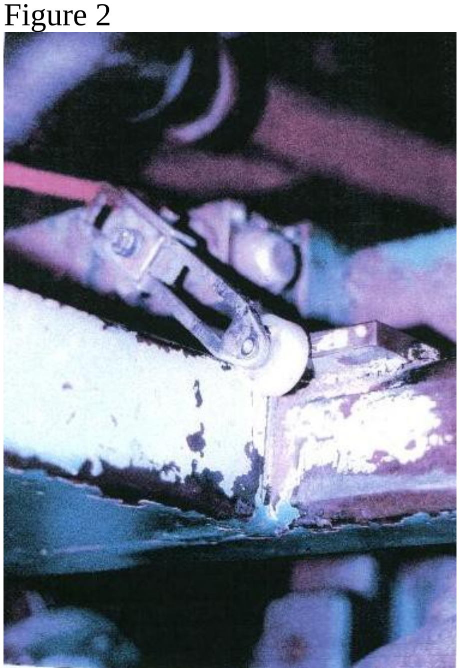
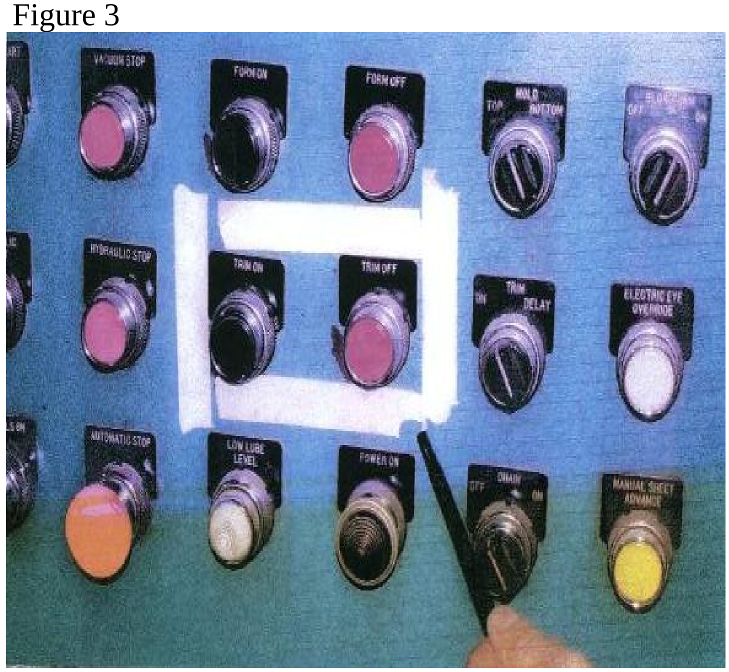


Figure 3



The second safeguard was an OFF switch on the control panel. There was one problem with this. There were 4 separate OFF-switches. In certain sequences, each of the first 3 switches controlled one part of the machine: heating unit, cutting unit, pressing unit. The 4th switch was a master OFF switch. This is the “mushroom” switch in Figure 3. The 4th switch did not, however, control the cutting blades. To repeat: the Master shutoff did not shut off everything. The switch that did was later identified by placing masking tape around it. But this too had a problem associated with it. It did not stop the cutting blades when the blades had begun a cycle. With the jam under the blades, the blades had begun a cycle of coming down which they completed after the jam was removed. In the process of finishing their cycle, they cut the poor machinist’s hands. The machine had state-of-the art industrial controls with approximately 50 separate relay systems controlling all of the motions of the machine. A complete dead stop condition would have stopped the cutting cycle of the blades. With the more modern PLC control, there is a "drop dead" command that monitors all stops in all parts of the machine. The drop-dead command via PLC's understands the need to finish a cycle vs. the need to protect a human. With the new PLC control, a drop-dead command is just that. Everything drops dead completely. One simple command shuts down all phases of all parts of the machine. See [4].

CASE 3: A WOMAN GRINDS LENSES AND ACCIDENTALLY ACTIVATES THE MACHINE

A company advertises "Come to us and get your glasses made within the hour". The glasses are often made by a technician whose only qualifications are to load the glass blanks into a machine and press certain codes into the machine in order to instruct the machine as to how to grind the lens needed. These codes come from the prescription written by the ophthalmologist that the patient went to earlier. What is unusual about this case is that the machine is controlled both by PLC's and by a full microprocessor. There is almost nothing the technician can do to compromise their safety. Yet, an accident did occur. The technician is putting the lens blank into a "chuck" to hold it. She has already punched in the appropriate codes for grinding. While she is adjusting the blank with one hand, her other hand accidentally hits the ON switch. The lens blank starts to spin in the chuck and cuts the technician's hand. Luckily, the damage was small.

In the future, the company prevented this type of accident from re-occurring. In their new machine, the technician places the blank into the chuck. There are 2 ON-switches in series. She can NOT turn the machine on, even if she purposely hits one of the ON switches. Once everything is ready, the technician must turn on both ON buttons simultaneously. The buttons are located at each end of the machine. She can NOT hit both buttons with just one hand. She must touch each button at different ends of the machine with each of her hands. Thus, no hand is in the way of the spinning chuck. This common sense safety feature prevents an accident that even PLC and microprocessor controls could not prevent.

CONCLUSIONS

(1) Friendly sabotage of industrial safety features are a fact of life. They are motivated by worker fear and/or laziness. No amount of training can change this.

(2) Friendly sabotage can be cured by strong regulations of a workers actions by protocols set by the machine designer and implemented by PLC controls designed into the machine to allow some input from the worker but to never allow him to go beyond the point deemed safe.

(3) Even PLC's are not the only answer to worker safety. Common sense in the understanding of the human/machine interaction can be a better safety feature then even the most sophisticated PLC controls.

REFERENCE

(1) See “Decrypting control system drawings”, Ryan Rosandich, EC&M, p 30, December 1998. See also
(2) See, for example, schmersalusa.com, sti.com, pinnaclesystems.com, baneng.com, and many others.
(3) Forensic Engineering Investigation, Randall K. Noon, CRC Press (2001), ISBN 0849309115.
(4) Electric Machines, Jimmie Cathey, McGraw-Hill (2001), ISBN 0-07-242370-6. See also Electric Machinery, A. Fitzgerald, C. Kingsley, and S. Umans, McGraw-Hill (1983), ISBN 0-07-021145-0.

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